Progress In Electromagnetics Research Letters, Vol. 111, 85–91, 2023

Compact Ultra-Wideband Circularly Polarized Crossed-Dipole Antenna with Wide Angle Coverage

Chao Li[1, 2, *], Ze-Hong Yan[1], and Wei Hu[1]

Abstract—This letter presents a compact ultra-wideband circularly polarized (CP) crossed-dipole antenna with enhanced axial-ratio beamwidth (ARBW) and half-power beamwidth (HPBW). It consists of four modified arms which are fed by vacant-quarter phase delay rings to excite CP radiation. Four parasitic elements are utilized rotationally between the dipoles and the reflector. Not only does inducing vertical currents on the parasitic patches excite additional impedance resonance to realize an ultra-wideband operating, but also reinforced radiation is obtained to improve the ARBW and HPBW. The experimental results show that the proposed antenna realizes a -10 dB impedance bandwidth of 134.3% and a 3 dB axial-ratio (AR) bandwidth of 115.0%, while holding a compact volume of $0.25\lambda_L \times 0.25\lambda_L \times 0.09\lambda_L$ (λ_L: wavelength at the lowest operating frequency). Furthermore, an HPBW and ARBW of more than 110° and 160° are realized within a broad operating band of 67.5% and 55.0%, respectively.

1. INTRODUCTION

Compared with linearly polarized antennas, circularly polarized (CP) antennas are very popular to some particular wireless communication applications due to the abilities of combating multipath fading and mitigating polarization mismatch, such as wireless local network (WLAN), unmanned aerial vehicles (UAV), and global navigation satellite system (GNSS) [1, 2]. The basic principle for designing a CP antenna, for example, is that a pair of electric fields with equivalent amplitude and orthogonal phase are implemented in the form of single-feed or dual-feeds. In most cases, the single-feed antenna has a relatively simple feeding configuration, while the dual-feed antenna always obtains a better axial-ratio bandwidth; however, an additional hybrid coupler or power network is needed, which will significantly increase the system size [3, 4]. A new optimization method of solving a phase retrieval problem is proposed in [5], and satisfactory results have been obtained. In summary, a broadband CP antenna with compact size and simple structure is highly demanded in the antenna field.

Extensive research works have been done to enhance the operating bandwidth of CP antennas. It is a direct method to apply multiple resonators with different operating frequencies. By combining the responses simultaneously, the overall bandwidth can be increased. A dielectric antenna obtains a bandwidth of 21% by using coplanar resonator [6]. Replacing linear arms with wider planar dipole arms is also an effective way to enhance the bandwidth. For example, an elliptical dipole antenna with a composite cavity achieves a bandwidth of 96.6% [7]. Recently, based on a similar principle a modified cavity CP antenna was reported to achieve a bandwidth of 125.2% at the cost of increasing footprint and system complexity [8].

In addition to the broadband operating performance, with a wide axial ratio beamwidth (ARBW), CP antennas are more competitive to ensure sufficient communication links, especially when the antenna

Received 14 February 2023, Accepted 21 June 2023, Scheduled 15 July 2023
* Corresponding author: Chao Li (lcha@163.com).
[1] National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, China. [2] Xi'an Electronic Engineering Research Institute, Xi'an, China.

carrier has a variety of position changes. By using an excited array of metallic metasurface cells, antenna realizes a wide ARBW of 205° [9]. Furthermore, using the parasitic elements, a wide ARBW about 196° can be obtained [10]. Nevertheless, most of the proposed designs exhibit an excellent ARBW within a limited frequency band.

Half power beamwidth (HPBW) is also a key parameter apart from the ARBW for wide-angle applications. Utilizing metal nonplanar radiators is an effective approach to realize wide HPBW. Radiator is omposed of two pairs of orthogonal curved arms, and an HPBW of 196° can be obtained [11]. Using nonuniformly compressed high-order mode is another approach to enhance the HPBW. In [12], an HPBW of over 110° was achieved by placing dipoles in double X shape and exciting nonuniformly compressed high-order mode. However, all of the aforementioned antennas either pursued compact size, wide impedance or pursued wide beamwidth, but none of them met the above performances at the same time.

Inspired by above researches, a crossed dipole CP antenna with ultra-wideband impedance, AR bandwidth, and wide ARBW is developed by introducing four elaborately designed parasitic metallic elements. A prototype was fabricated and tested to verify this design. The experimental results indicate that our presented ultra-wideband CP antenna has an outstanding impedance bandwidth of 134.3% (1.36–6.73 GHz) and AR bandwidth of 115.0% (2.1–6.7 GHz). Furthermore, a wide ARBW of over 160° can be maintained in a broadband frequency range from 2.3 GHz to 4.5 GHz. These features make the proposed CP antenna a potential candidate for various modern wireless communication systems.

2. ANTENNA CONFIGURATION AND DESIGN

The configuration of the ultra-wideband CP antenna is shown in Figure 1. The antenna comprises two pairs of modified dipoles, four modified parasitic elements, a feeding coaxial cable, and a ground plane. The modified dipole arms are etched on the top and bottom layers of a Rogers RO4003 substrate with a thickness of $h_1 = 1\,\text{mm}$ and a relative permittivity of $\varepsilon_r = 3.55$. Dipole arms are placed with a distance of 19 mm right on the reflector. As depicted in Figure 1, four dipole arms are arranged vertically to each other, and every arm is made up by the combination of a half-ellipse and a rectangle. Meanwhile, adjacent arms on same sides of the substrate are connected with a vacant-quarter ring which has a ring length about $\lambda_g/4$. Besides, by connecting top-layer and bottom-layer rings to the inner pin and outer conductor of a coaxial cable, respectively, a 90° phase shift is produced between the adjacent arms at the same layer, and CP radiation is generated [13]. To further improve the CP antenna performance, four combined coupling elements are introduced besides the dipole arms and sequentially arranged to the upper substrate with a distance d_1 from the arms. Each parasitic element is composed of a vertical rectangle-shaped patch and a modified horizontal triangle patch. The horizontal patches are etched on the bottom layer of the substrate. Meanwhile, the vertical plates are fabricated on the inner surfaces of four rectangle substrates and soldered to the ground plane as well as the horizontal patches. Each vertical plate has a height of h and a width of w_2. Besides, the rectangle ground plane ($l \times l$) is soldered to the 50 Ω-coaxial cable and performed as a reflector to realize an unidirectional radiation pattern. The optimal parameters of the CP antenna are listed in Figure 1. Furthermore, the overall volume of the CP antenna is $56 \times 56 \times 21\,\text{mm}^3$.

To analyze the CP mechanism, the simulated current distributions on the modified dipoles and the combined coupling elements at 2.3 GHz are shown in Figure 2. As indicated in Figure 2, at $t = 0$, the surface currents with equivalent amplitude and orthogonal phase are excited orthogonally on the arms by using the vacant-quarter rings. Then, at $t = T/4$, surface currents on the arms along y axis are towards the $-y$ axis, and there is a current direction reversal compared with the moment $t = 0$. The same principle can be found at $t = T/2$ and $t = 3T/4$. Obviously, with the increase of phase, the current rotates counterclockwise and generates a right-hand circularly polarized (RHCP) radiation. By mirroring the antenna structure reference to the y-axis, left-hand circularly polarized (LHCP) radiation can be realized. On the other hand, as depicted in Figure 2, the currents on one pair of the coupling patches flow in the same direction as those on the adjacent dipole arms. Meanwhile, the currents on the remaining coupling patches flow in the opposite direction to those on the corresponding dipole arms. The current amplitudes of the dipole can thus be balanced by adding a coupling patch, leading to a new impedance resonance, which was not possible in the traditional design with absence of the coupling

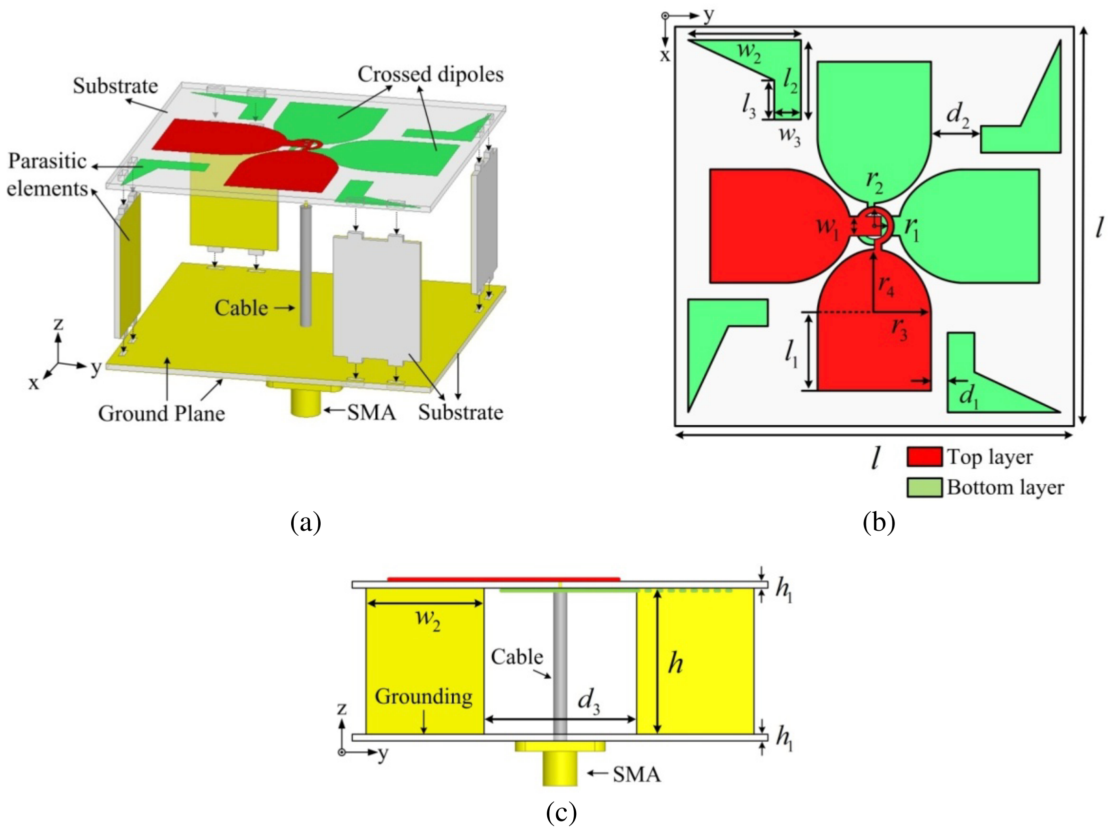


Figure 1. Configuration and detailed dimensions of the crossed-dipole antenna. (a) Perspective view. (b) Top view. (c) Side view. $L = 56$ mm, $h = 19$ mm, $l_1 = 10$ mm, $l_2 = 12$ mm, $l_3 = 6$ mm, $w_1 = 3$ mm, $w_2 = 17$ mm, $w_3 = 3.5$ mm, $r_1 = 2$ mm, $r_2 = 2.9$ mm, $r_3 = 8.5$ mm, $r_4 = 10.5$ mm, $d_1 = 2.5$ mm, $d_2 = 7.5$ mm, $d_3 = 22$ mm, and $h_1 = 1$ mm.

patch. Moreover, as can be noticed in Figure 2, currents in the vertical direction are concentrated on the parasitic elements, and the vertical currents radiate a figure-∞ shaped and a figure-O shaped patterns in the E- and H-planes, respectively. Furthermore, the crossed-dipoles provide an unidirectional cardiac shaped radiation pattern pointing to the boresight direction. Considering the proposed CP antenna, the summed radiation field will be reinforced near low elevation angles with gain barely changed in boresight direction, resulting in a better identical radiation pattern in upper hemisphere space. As a consequence, an expected 3 dB HPBW of more than 110° is obtained. Moreover, due to the vertical currents, the ARBW is also significantly improved to over 160° within a broad operation band from 2.3 to 4.5 GHz.

3. RESULTS AND DISCUSSION

To validate the design principle, a prototype of the ultra-wideband CP antenna was fabricated and tested, and pictures of the prototype are illustrated in Figure 3. The S parameter was measured with an Agilent N5244A network analyzer. The radiation patterns, axial-ratio, and gain were measured in a near field antenna measurement system at Xidian University. Figure 4 shows the simulated and experimental parameters including reflection coefficient, AR bandwidth, ARBW, and boresight gains. The -10 dB impedance bandwidth and AR bandwidth (for AR < 3 dB) are measured to be 134.3% (1.36 GHz–6.73 GHz) and 115.0% (2.1 GHz–6.7 GHz), respectively. The slight deviation between simulation and measurement may attribute to the assembly errors and soldering effect. It is worth emphasizing that the entire 3 dB axial-ratio bandwidth falls totally in the spectral range of the -10 dB impedance bandwidth,

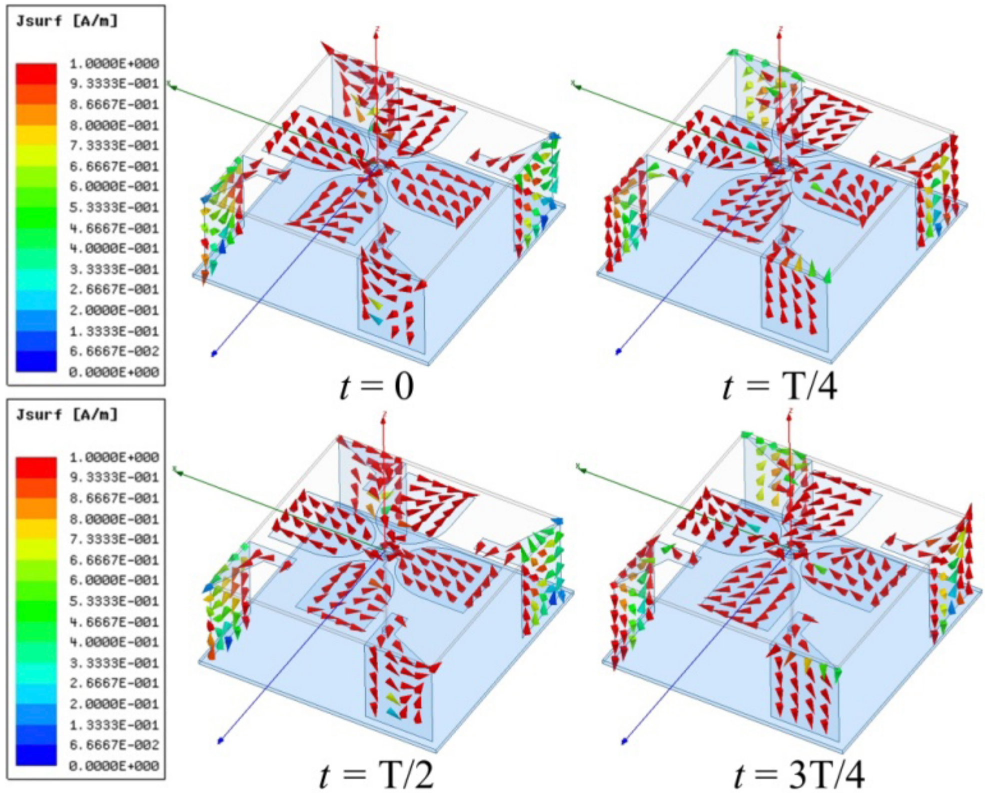
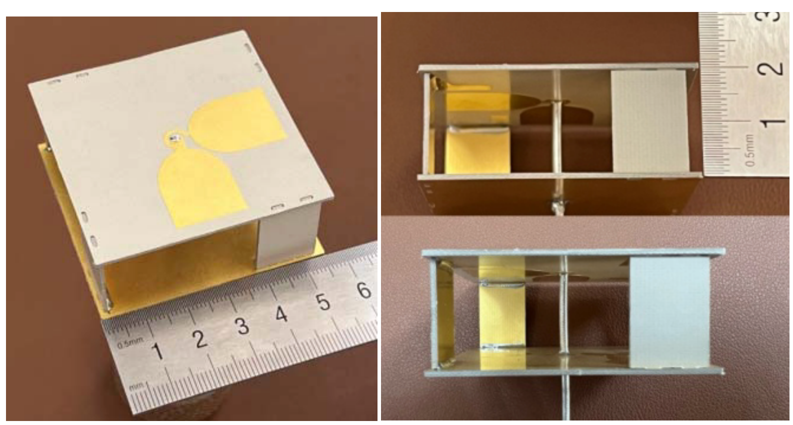


Figure 2. Surface current distributions of the presented antenna at 2.3 GHz.



(a) (b)

Figure 3. Prototype of the presented CP crossed-dipole antenna. (a) Perspective view. (b) Side view.

which means that the antenna can operate in both wide impedance bandwidth and AR bandwidth simultaneously. The simulated and measured 3 dB ARBWs at 2.3 GHz, 3.5 GHz, and 4.5 GHz are presented in Figure 4(b). As illustrated, the measured ARBW can be obtained more than 160° at different frequencies, and the maximum ARBW even exceeds 260° at 2.3 GHz, which indicates that the CP antenna keeps a broad ARBW and covers a very wide passband. As can be seen in Figure 4(c), the simulated and measured boresight gains of the antenna vary less than 3 dB within the entire 3 dB AR bandwidth.

Figure 5 shows the simulated and measured radiation patterns in *xoz*- and *yoz*-planes, at frequencies

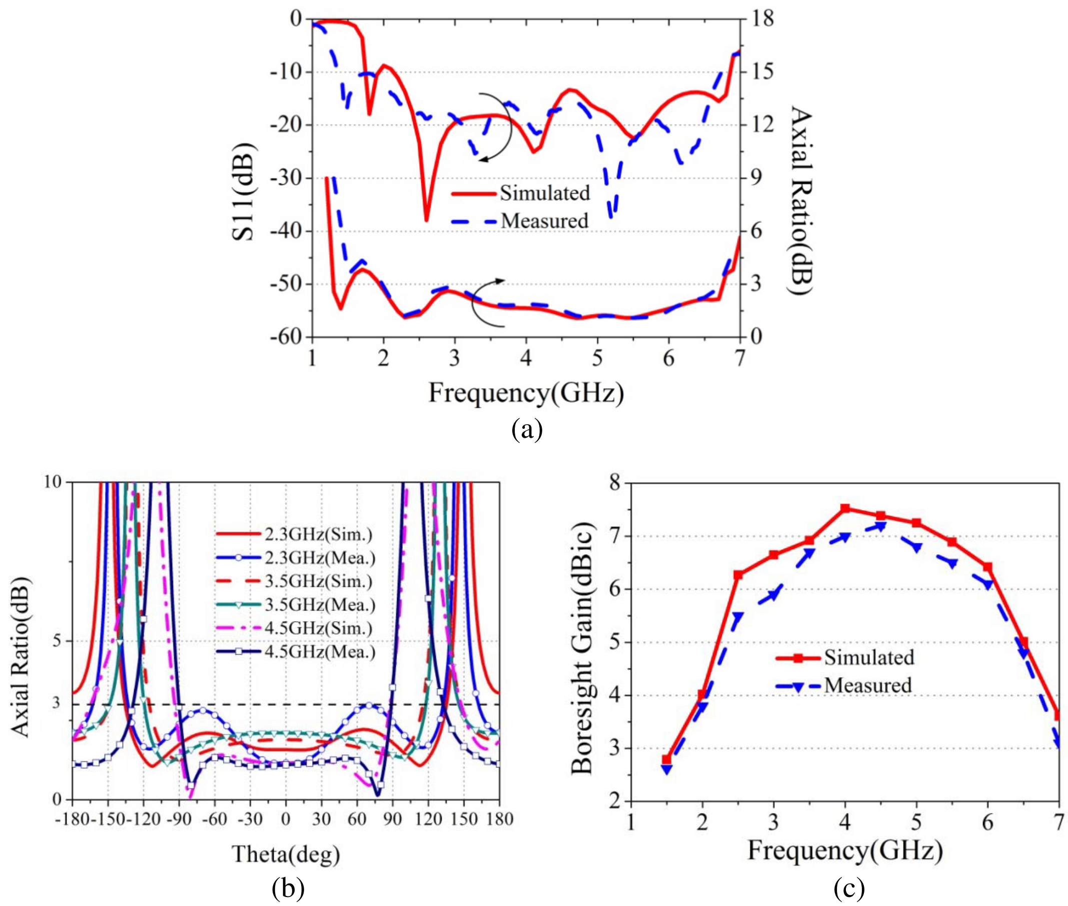


Figure 4. Simulated and measured parameters for the presented antenna. (a) Reflection coefficient and axial ratio, (b) 3 dB ARBW, (c) boresight gains.

Table 1. Comparison of the wideband CP antennas.

Ref.	Size (λ_L^3)	Impedance Bandwidth	AR Bandwidth	Maximum ARBW (Bandwidth)	Maximum HPBW (Bandwidth)	Peak Gain
[7]	$0.87 \times 0.87 \times 0.17$	105.6%	96.6%	156° (> 66°: 31.5%)	NA	12.0 dBic
[8]	$0.74 \times 0.74 \times 0.17$	125.2%	120.1%	NA	70° (NA)	12.2 dBic
[9]	$0.93 \times 0.93 \times 0.024$	17.0%	14.5%	205° (> 150°: 13.3%)	NA	NA
[10]	$0.29 \times 0.29 \times 0.07$	78.3%	63.4%	196° (> 120°: 50.7%)	154° (> 110°: 61.1%)	4.5 dBic
[11]	$0.35 \times 0.35 \times 0.10$	55.8%	70.9%	202° (> 134°: 42.8%)	113° (> 96°: 40.0%)	5.2 dBic
[12]	$1.86 \times 1.86 \times 0.25$	11.29%	1.68%	134° (> 118°: 1.68%)	111° (> 109°: 10%)	5.21 dBic
Prop.	$0.25 \times 0.25 \times 0.09$	134.3%	115.0%	260° (> 160°: 55.0%)	122° (> 110°: 67.5%)	7.2 dBic

NA: not available λ_L: wavelength at the lowest operating frequency

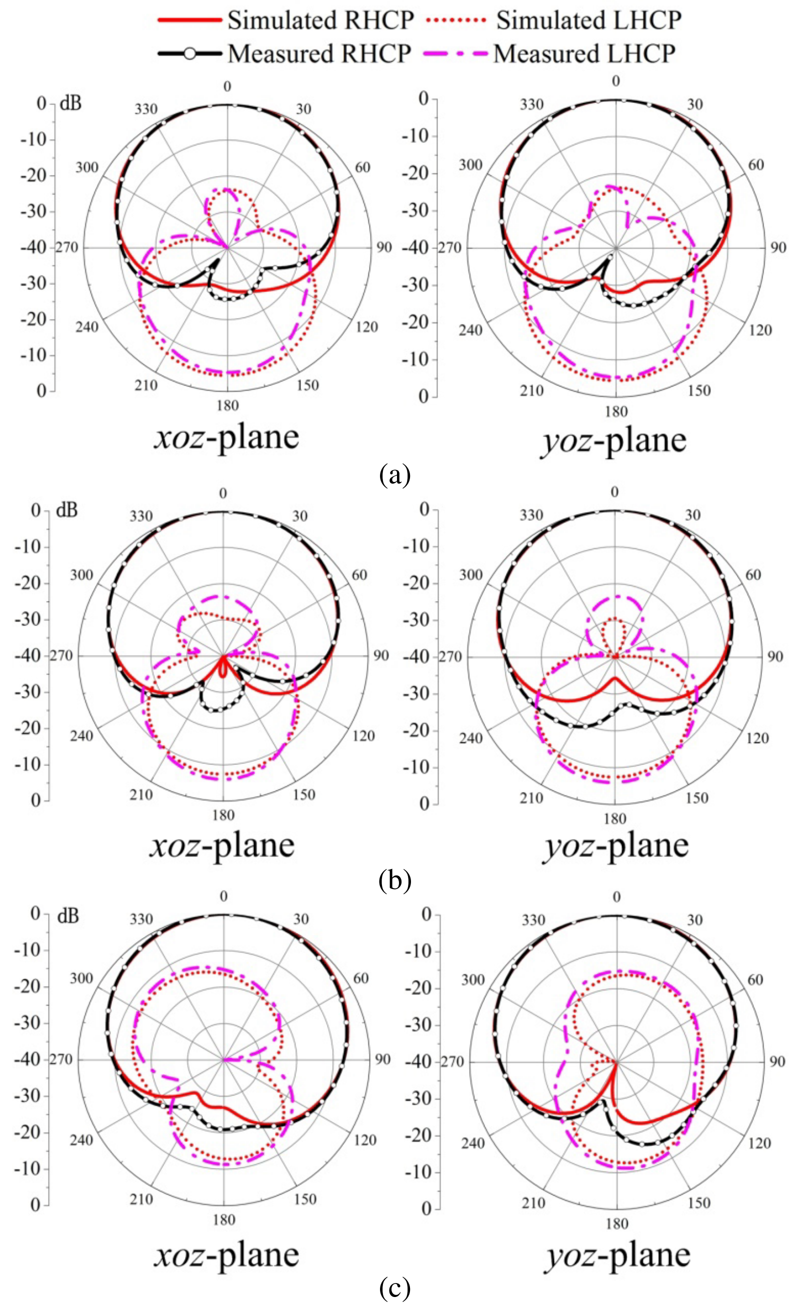


Figure 5. Simulated and measured normalized radiation patterns at (a) 2.1 GHz, (b) 3.5 GHz, (c) 4.8 GHz.

of 2.1 GHz, 3.5 GHz, and 4.8 GHz, respectively. We can find that symmetrical and unidirectional radiation patterns are realized within a wide operating band. In addition, the fields of cross-polarization are weaker than that of the co-polarization by over 17 dB in the boresight direction. In both *xoz*- and *yoz*-planes, a wide HPBW of more than 110° is achieved at 2.1 GHz, 3.5 GHz, and 4.8 GHz. Besides, it can also be noticed that the radiation fields at backward direction of the cross-polarization are a bit stronger, mainly due to the vertical patches connected to the ground plane.

Table 1 summarizes the comparison results between the presented design and previously reported wideband CP antennas. It is concluded that the presented antenna realizes a desired wide (impedance, ARBW and HPBW) bandwidth with in a compact structure. Even if the design in [8] has a wider AR bandwidth, our presented configuration gets a much smaller volume than that of the antenna in [8]. Thus, our proposed antenna still has the most outstanding overall performance.

4. CONCLUSION

An ultra-wideband CP crossed-dipole antenna with a simple structure is presented. Not only does inducing vertical currents on the parasitic patches lead to a compact antenna size by extending the current distribution of the radiating dipoles and excites extra impedance resonant to realize an ultra-wideband operation, but also reinforced radiating fields are obtained to improve the HPBW and ARBW. Reasonable agreement is achieved between the simulated and experimental results, indicating a -10 dB impedance bandwidth of 134.3% and a 3 dB AR bandwidth of 115.0%. Furthermore, an HPBW and ARBW of more than 110° and 160° are realized within a broad operating band of 67.5% and 55.0%, respectively. Such an ultra-wideband CP crossed dipole antenna is a promising candidate for applications in various modern wireless systems like GNSS, UAV, radar, and S/C-band satellite communication system.

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